Data Communication and Net-Centric Computing

COSC 1111/2061/1110

Lecture 3

Data Transmission and Encoding

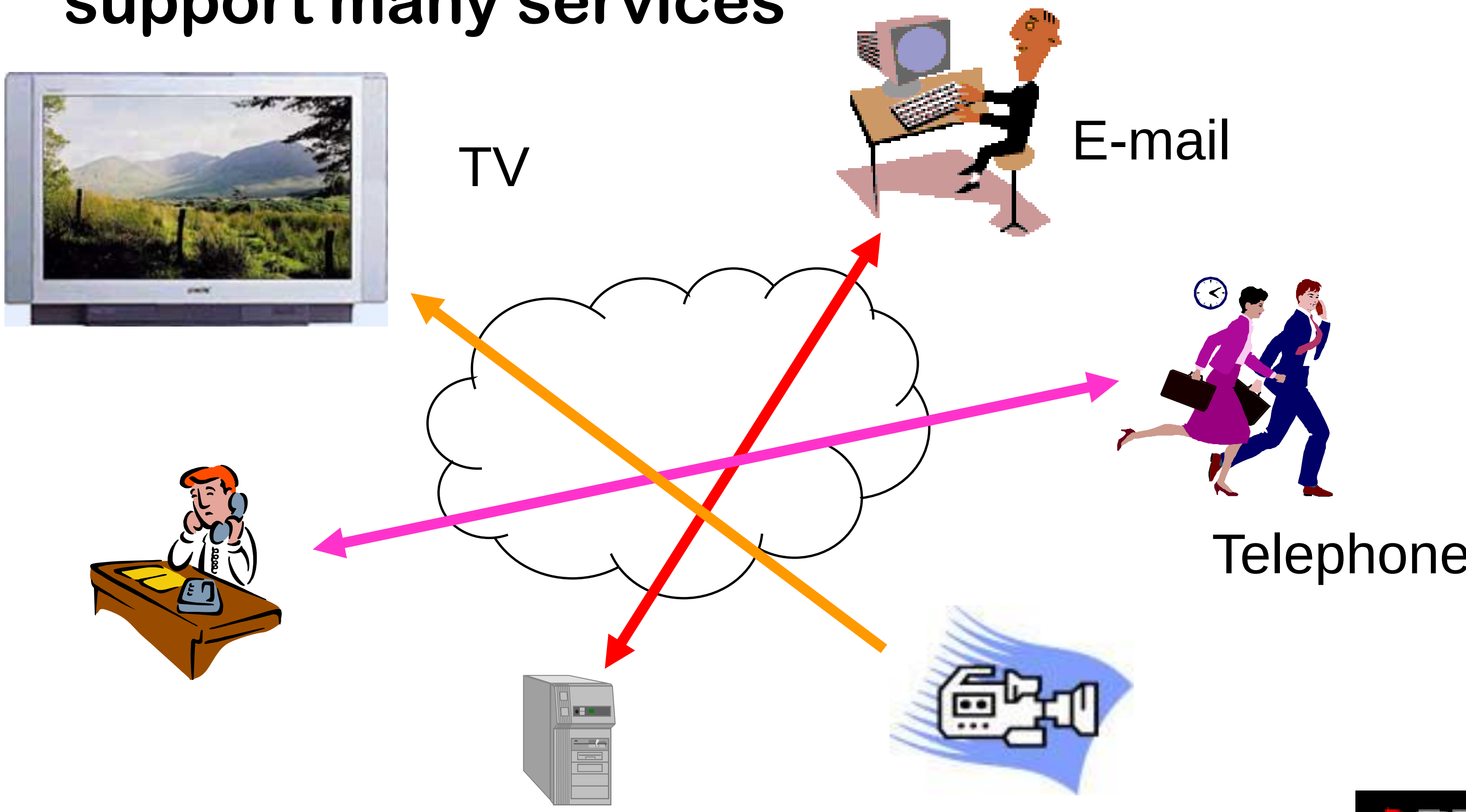
Lecture Overview

- During this lecture, we will understand
  - Digital transmission basics
  - Time and Frequency domain concepts
  - Encoding concepts
  - Digital data, digital signal
  - Analog data, digital signal
  - Digital data, analog signal
  - Analog data, digital signal

- Recommended reading
  - Chapter 3,4,5 (Stallings)

Digital Networks

- Digital transmission enables networks to support many services



Questions of Interest

- How long will it take to transmit a message?
  - How many bits are in the message (text, image)?
  - How fast does the network/system transfer information?
- Can a network/system handle a voice (video) call?
  - How many bits/second does voice/video require? At what quality?
- How long will it take to transmit a message without errors?
  - How are errors introduced?
  - How are errors detected and corrected?
- What transmission speed is possible over radio, copper cables, fiber, infrared, ...?

Data Delivery Delay

- L number of bits in message
- R bps speed of digital transmission system
- L/R time to transmit the information
- t_{prop} time for signal to propagate across medium
- d distance in meters
- c speed of light ($3\text{x}10^8$ m/s in vacuum)

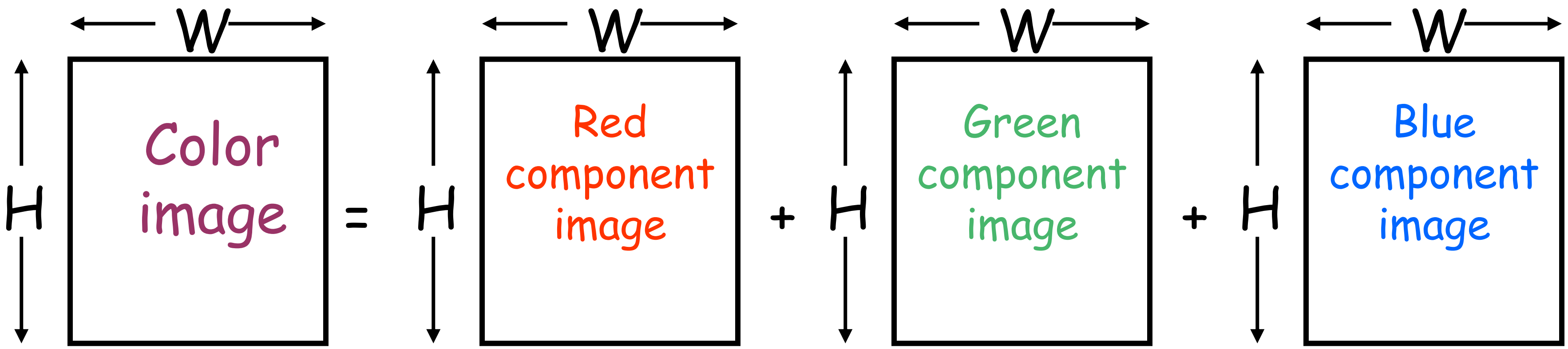
$$Delay = t_{prop} + L/R = d/c + L/R \text{ seconds}$$

- Use data compression to reduce L
- Use higher speed modem to increase R
- Place server closer to reduce d

Compression

- Information usually not represented efficiently
- Data compression algorithms
  - Represent the information using fewer bits
  - Noiseless: original information recovered exactly
    - E.g. zip, compress, GIF, fax
  - Noisy: recover information approximately
    - JPEG
    - Tradeoff: # bits vs. quality
- Compression Ratio
  - #bits (original file) / #bits (compressed file)

Color Image



Total bits = 3 × H × W pixels × B bits/pixel = 3HWB bits

Example: 8×10 inch picture at 400 × 400 pixels per inch^2

400 × 400 × 8 × 10 = 12.8 million pixels

8 bits/pixel/color

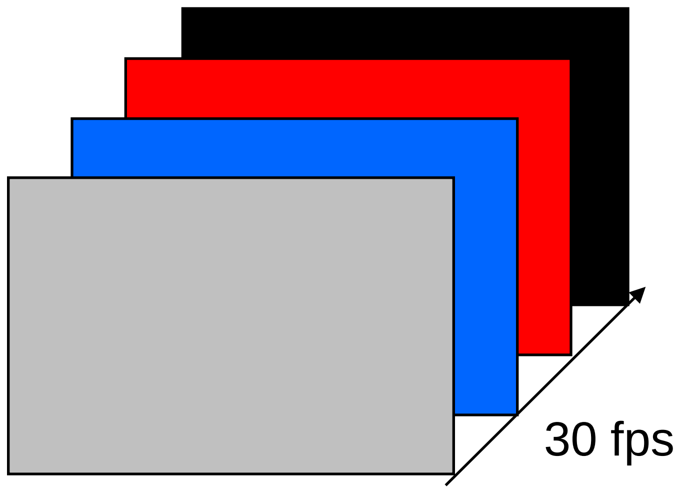
12.8 megapixels × 3 bytes/pixel = 38.4 megabytes

Examples of Block Information

Type	Method	Format	Original	Compressed (Ratio)
Text	Zip, compress	ASCII	Kbytes-Mbytes	(2-6)
Fax	CCITT Group 3	A4 page 200x100 pixels/in^2	256 kbytes	5-54 kbytes (5-50)
Color Image	JPEG	8x10 in^2 photo 400^2 pixels/in^2	38.4 Mbytes	1-8 Mbytes (5-30)

Video Signal

- Sequence of picture frames
  - Each picture digitized & compressed
- Frame repetition rate
  - 10-30-60 frames/second depending on quality
- Frame resolution
  - Small frames for videoconferencing
  - Standard frames for conventional broadcast TV
  - HDTV frames



Rate = M bits/pixel x (WxH) pixels/frame x F frames/second

Examples of Video Frames

QCIF videoconferencing

at 30 frames/sec =

760,000 pixels/sec

Broadcast TV

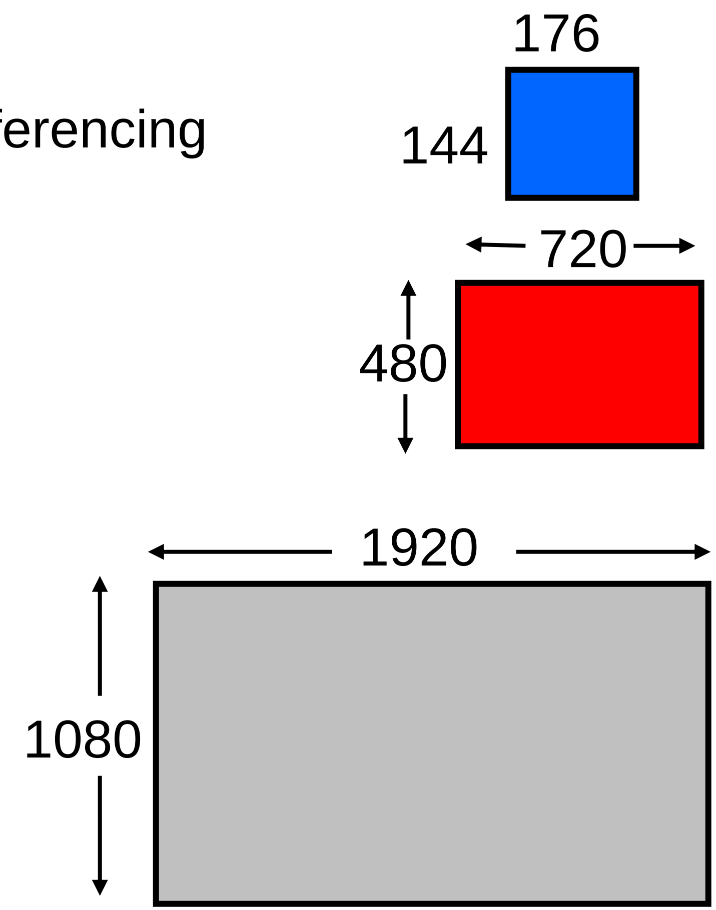
at 30 frames/sec =

10.4×10^6 pixels/sec

HDTV

at 30 frames/sec =

67×10^6 pixels/sec



Examples of Digital Video Signals

Type	Method	Format	Original	Compressed
Video Confer-ence	H.261	176x144 or 352x288 pix @10-30 fr/sec	2-36 Mbps	64-1544 kbps
Full Motion	MPEG2	720x480 pix @30 fr/sec	249 Mbps	2-6 Mbps
HDTV	MPEG2	1920x1080 @30 fr/sec	1.6 Gbps	19-38 Mbps

A Transmission System

Transmitter

- Converts information into *signal* suitable for transmission
- Injects energy into communications medium or channel
  - Telephone converts voice into electric current
  - Modem converts bits into tones

Receiver

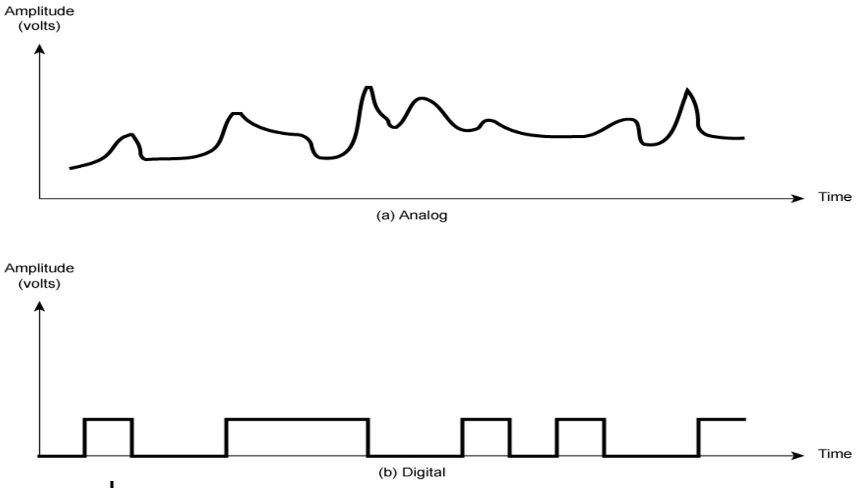
- Receives energy from medium
- Converts received signal into form suitable for delivery to user
  - Telephone converts current into voice
  - Modem converts tones into bits

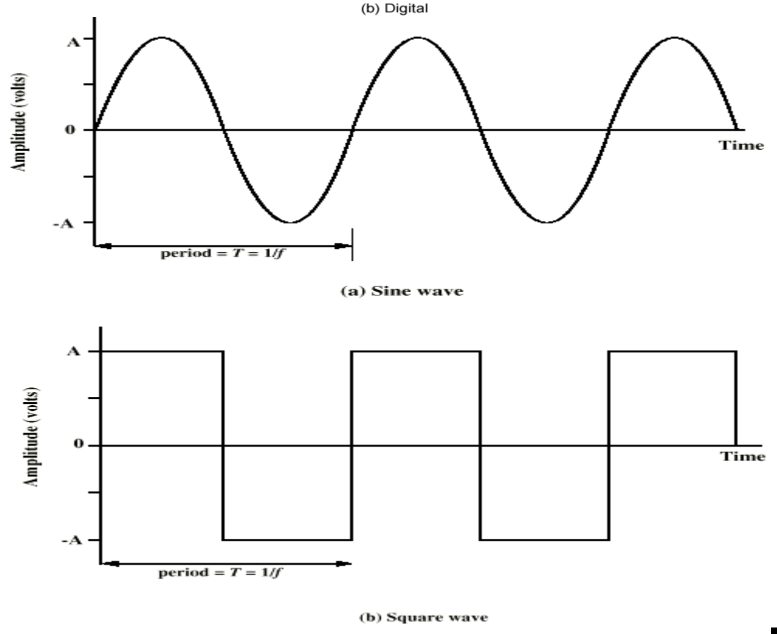
Transmission Basics

- Point-to-Point
  - Direct link, Only two devices share link
- Multi-point
- Simplex
  - Signals transmitted in one direction (TV)
- Half duplex
  - Both stations transmit, but one at a time
- Full duplex
  - Both stations transmit simultaneously (Phone)
- Transmission methods
  - Binary data transformed into electrical or optical signals

Time domain concepts

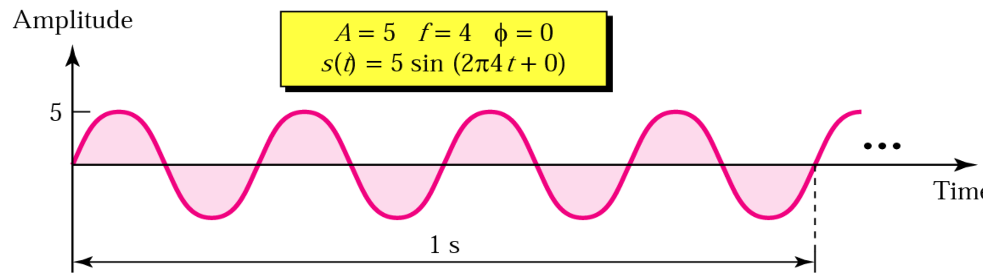
- Analog signal
  - Varies in a smooth way over time
- Digital signal
  - Maintains a constant level then changes to another constant level
- Periodic signal
  - Pattern repeated over time
- Aperiodic signal
  - Pattern not repeated over time

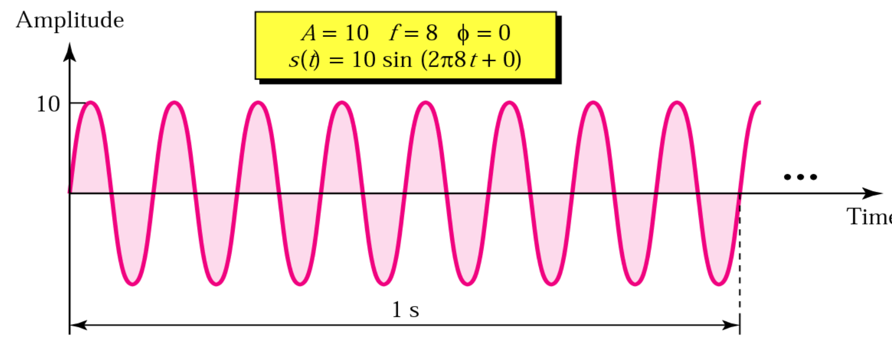


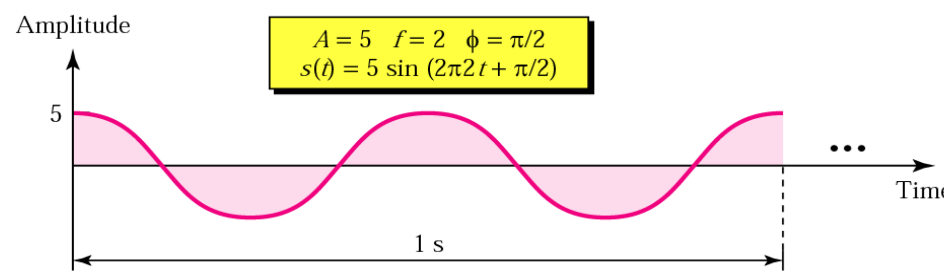


Varying Sine Waves
$s(t) = A \sin(2\pi ft + \Phi)$

- **Peak Amplitude (A)**
  - maximum strength of signal
  - volts
- **Frequency (f)**
  - Rate of change of signal
  - Hertz (Hz) or cycles per second
  - Period = time for one repetition (T)
  - T = 1/f
- **Phase (ϕ)**
  - Relative position in time

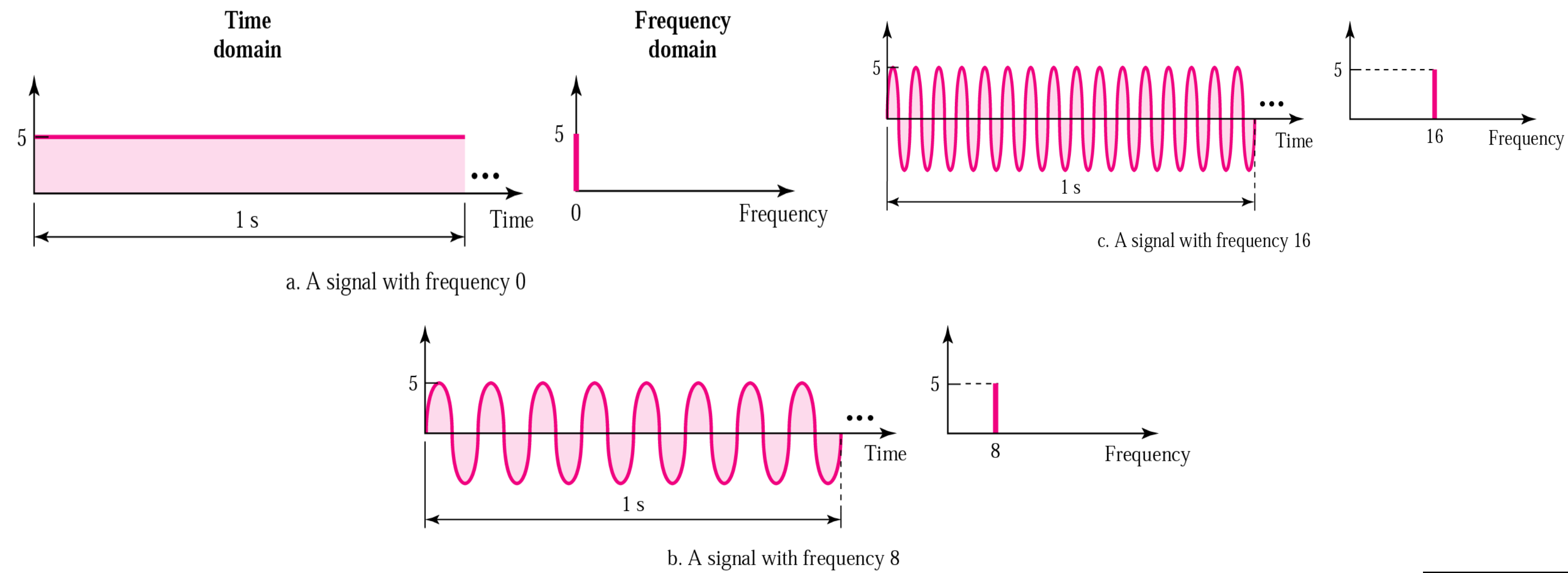






Frequency Domain Concepts

- Signal usually made up of many frequencies
- Components are sine waves
- Can be shown (Fourier analysis) that any signal is made up of component sine waves
- Can plot frequency domain functions



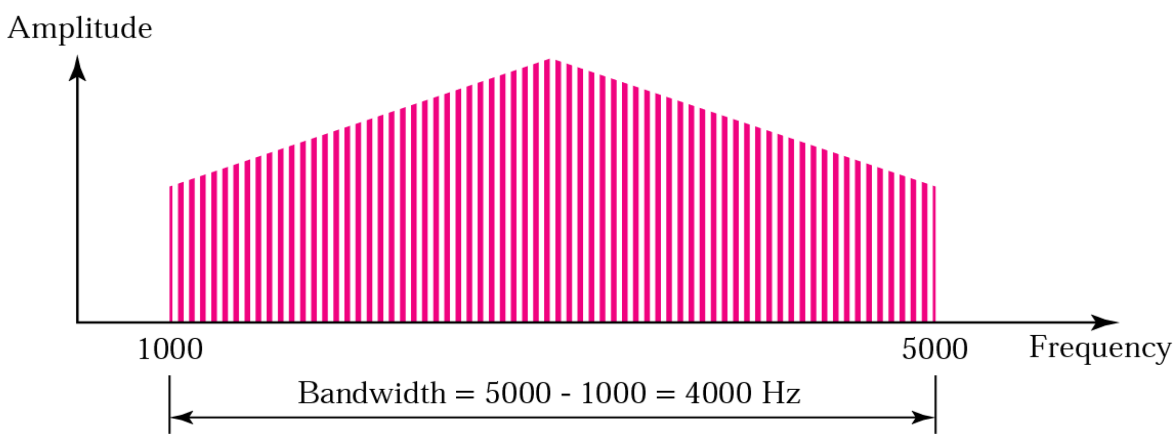
a. A signal with frequency 0

c. A signal with frequency 16

b. A signal with frequency 8

Bandwidth

- **bandwidth to refer to the property of a medium or the width of a single spectrum**
- It is the difference between the highest and the lowest frequencies that the medium can satisfactorily pass.
- higher the frequency of signal, the higher is the speed it changes

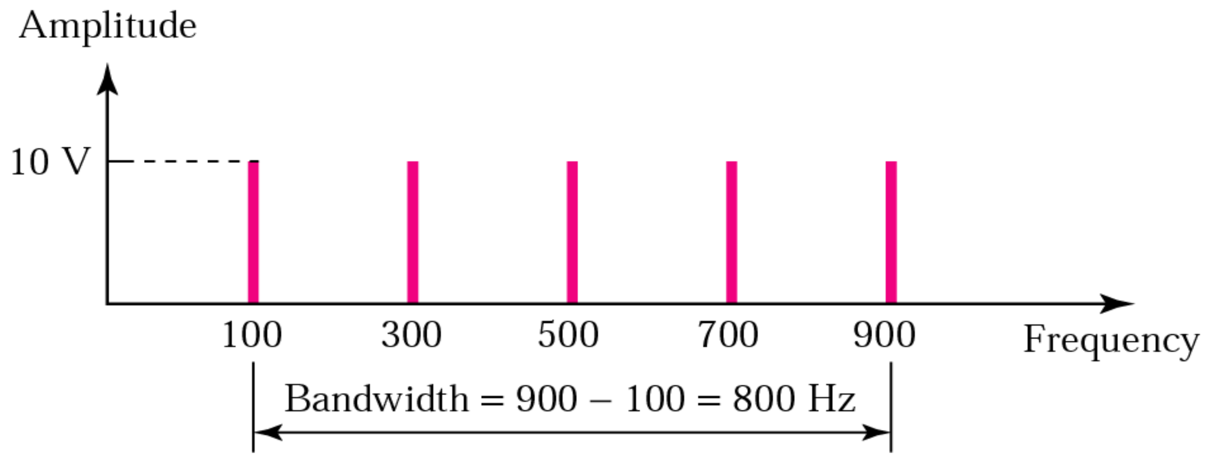


Example of Bandwidth

If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is the bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

$B = f_h - f_l = 900 - 100 = 800$ Hz

The spectrum has only five spikes, at 100, 300, 500, 700, and 900



Data Rate Limits: Nyquist Bandwidth

- How fast we can send data in bps?
  - Bandwidth available, level of signals, quality of signals
- Two theoretical formulas: Nyquist (noiseless), Shannon (noisy)
- For a noiseless channel, **Bit Rate= 2B $\log_2 M$**
- B is bandwidth of channel, M is signal levels used to represent data

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\text{Bit Rate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Consider the same noiseless channel, transmitting a signal with four signal levels. The maximum bit rate can be calculated as:

$$\text{Bit Rate} = 2 \text{ x } 3000 \text{ x } \log_2 4 = 12{,}000 \text{ bps}$$

Shannon Capacity Formula

- **In reality, we cannot have noiseless channel; the channel is always noisy.**
- **At given noise level, high data rate means higher error rate**
- **Capacity $C=B \log_2(1+SNR)$**
- **$SNR_{db}=10 \log_{10}$ (signal/noise) - (in decibels)**

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity is calculated as

$$C = B \log_2 (1 + SNR) = B \log_2 (1 + 0)$$

$$= B \log_2 (1) = B \times 0 = 0$$

We can't receive any data

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 Hz to 3300 Hz). The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2 (1 + SNR) = 3000 \log_2 (1 + 3162)$$
$$= 3000 \log_2 (3163)$$

$$C = 3000 \times 11.62 = 34{,}860 \text{ bps}$$

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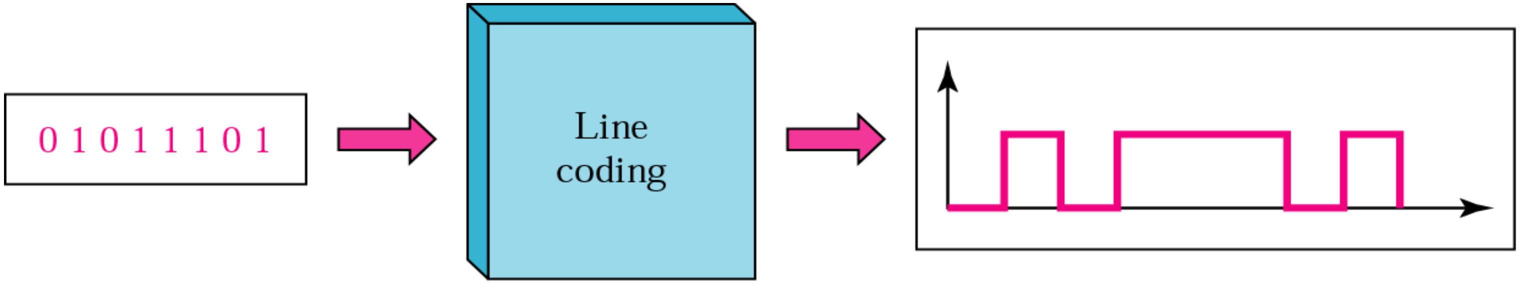
Data and signals

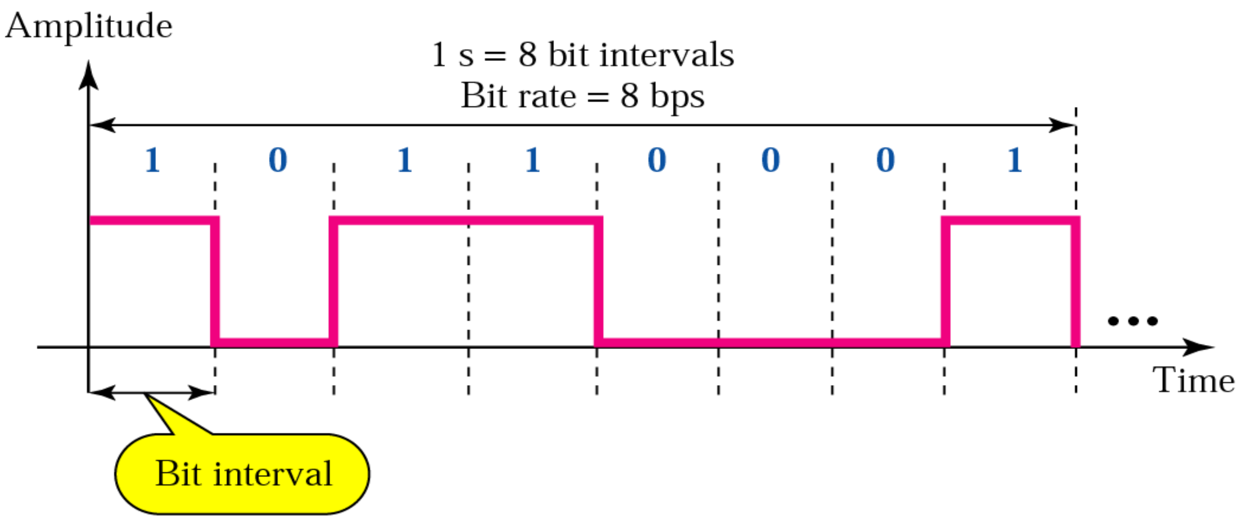
- Both analog and digital information can be encoded either as analog or digital signals
- Encoding
  - Mapping data bits to signal elements
- Digital signal
  - Sequence of discrete, discontinuous voltage pulses
  - Pulse is a signal element
- Modulation
  - Is a process of encoding source data onto a carrier signal with frequency *f*



Data Transmission Terminology

- Data element
  - A single binary one or zero
  - bit
- Data rate
  - Rate of at which data elements transmitted
  - Expressed in bits per second
- Unipolar
  - All signal elements have same sign
- Polar
  - One logic state represented by positive voltage the other by negative voltage
- Duration or length of a bit
  - Time taken for transmitter to emit the bit

Bit rate and bit interval



- *A digital signal has a bit rate of 2000 bps. What is the duration of each bit (bit interval)*

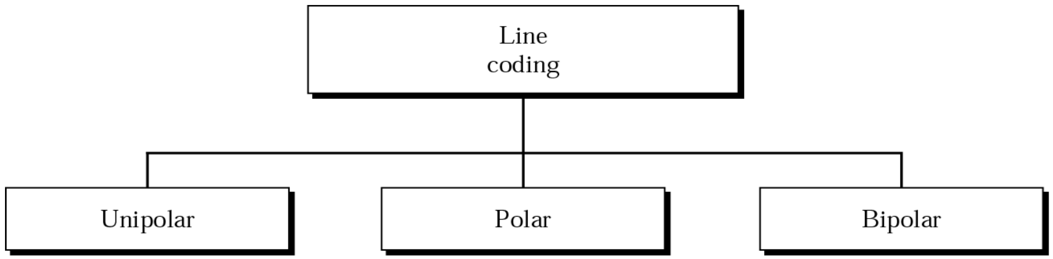
- **The bit interval is the inverse of the bit rate.**

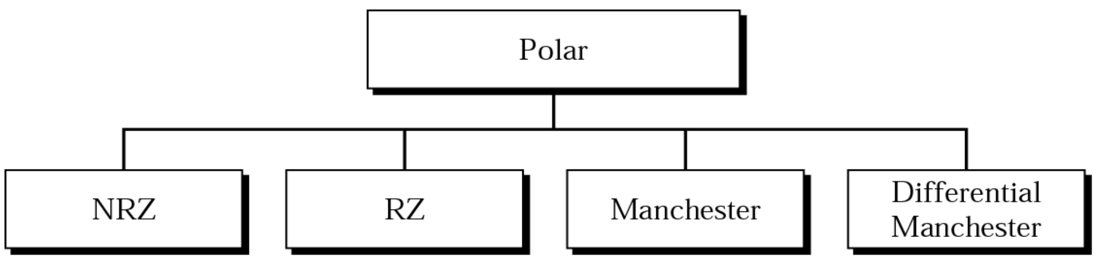
Bit interval = 1/ 2000 s = 0.000500 s
= 0.000500 x 10^6 ms = 500 μ s

Comparison of Encoding Schemes

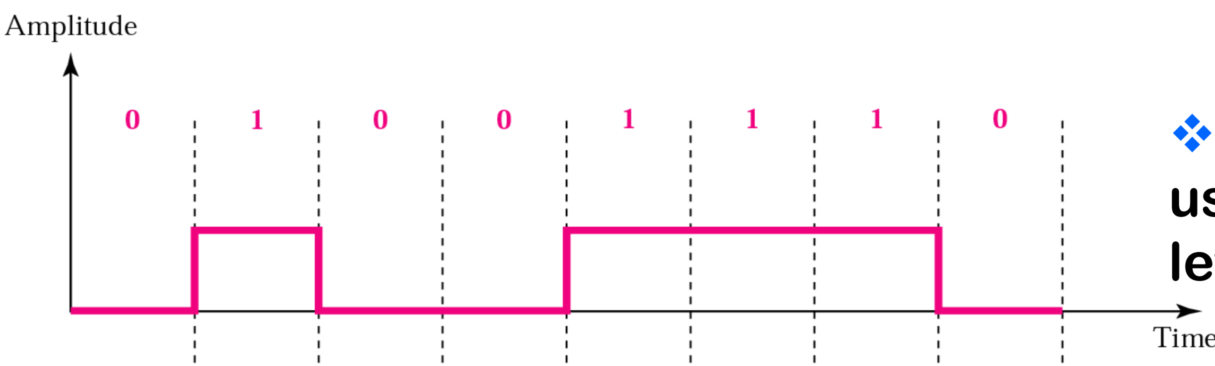
- Signal Spectrum
  - Lack of high frequencies reduces required bandwidth. Higher signal rate (& thus data rate) lead to higher BW
- Clocking
  - Synchronizing transmitter and receiver
- Error detection
  - Can be built in to signal encoding
- Signal interference and noise immunity
  - Some codes are better than others

Encoding Schemes





- Polar encoding uses two voltage levels (positive and negative)

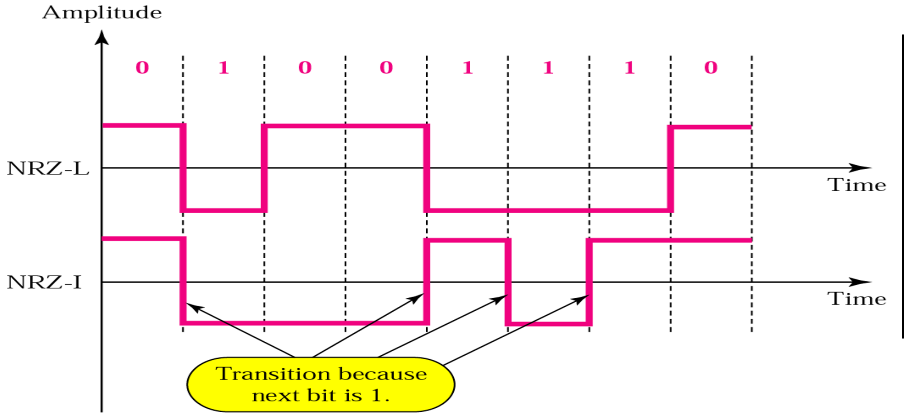


Unipolar encoding

- Unipolar encoding uses only one voltage level

Digital Data, Digital Signals

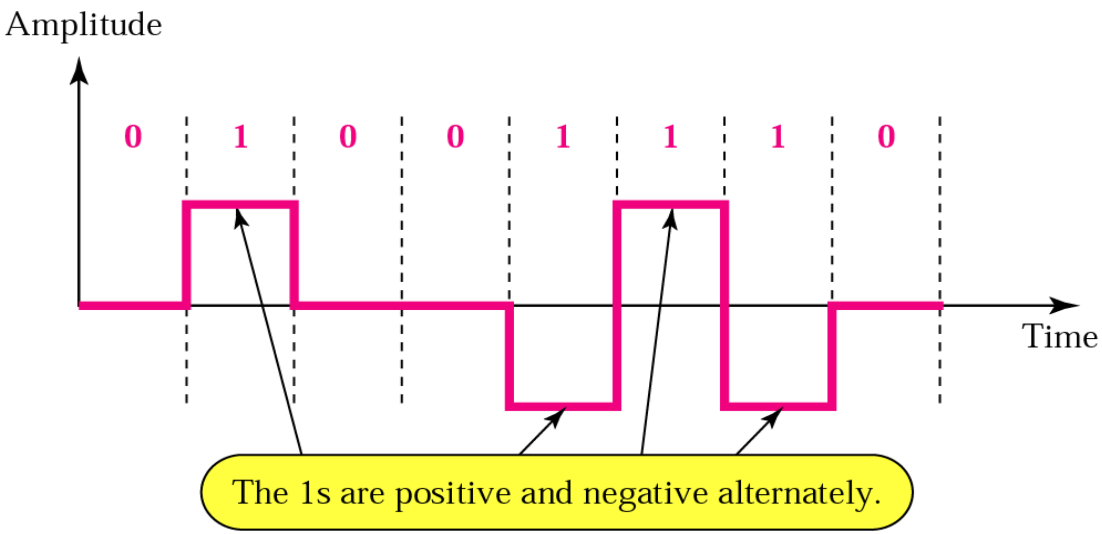
- Nonreturn to Zero Level (NRZ-L)
  - Used to generate or interpret digital data by terminals and other devices
    - 0 - high level
    - 1 - low level
- Nonreturn to Zero Invert on ones (NRZ-I)
  - Data are encoded as the presence or absence of a signal transition at the beginning of the bit time
    - 0 - no transition at the beginning of interval (one bit time)
    - 1 - transition at the beginning of the interval



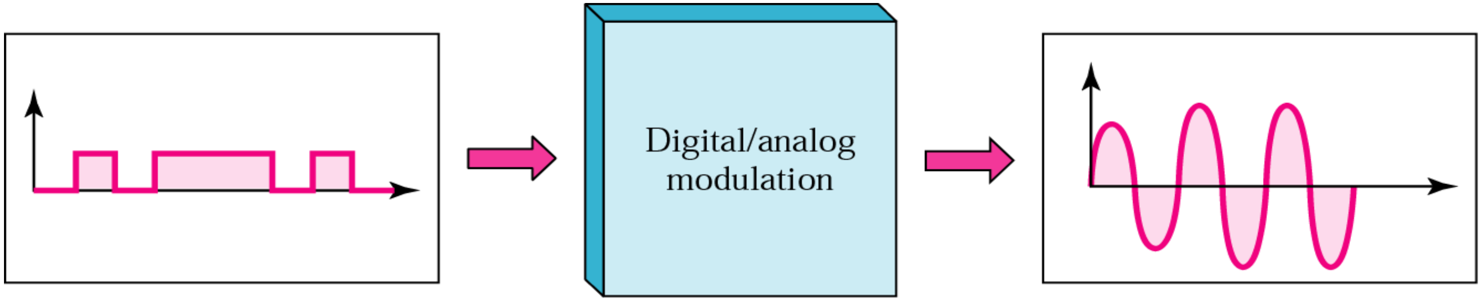
- Pros
  - Easy to engineer
  - Make good use of bandwidth
- Cons
  - Lack of synchronization capability
  - dc component

Bipolar Encoding

- Multilevel Binary
  - Use more than two signal levels
- Bipolar-AMI (Alternate Mark Inversion)
  - Binary 0 represents no line signal
  - Binary 1 represented by a positive or negative pulse, alternating for successive ones
- Not efficient as NRZ

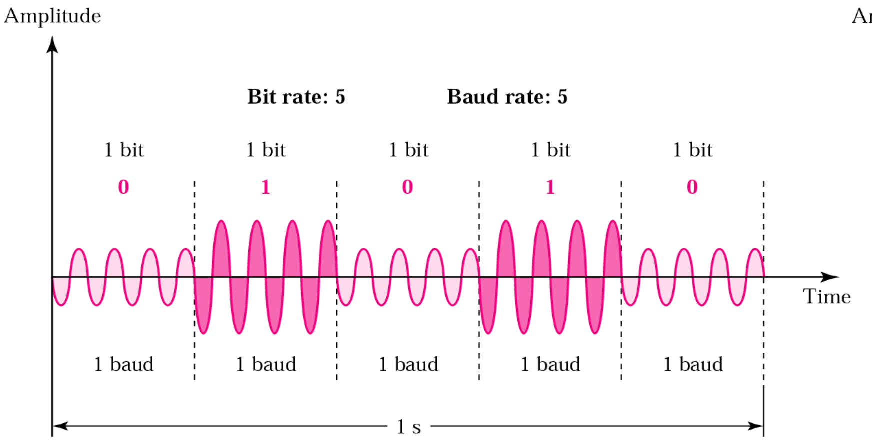


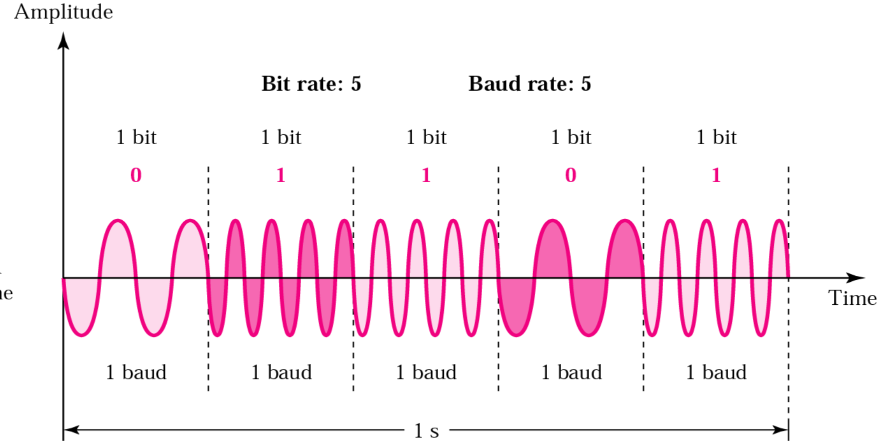
Digital Data, Analog Signals



- Transmitting digital data using analog signals
- Public telephone network - Voice frequency range of 300 to 3400 Hz
- Modulation involves operation on one or more of the three characteristics of a carrier signal
- Modulation techniques
  - Amplitude-shift keying (ASK)- apm of carrier signal varies
  - Frequency-shift keying (FSK)- freq of carrier signal varies
  - Phase-shift keying (PSK)- phase of carrier signal varies

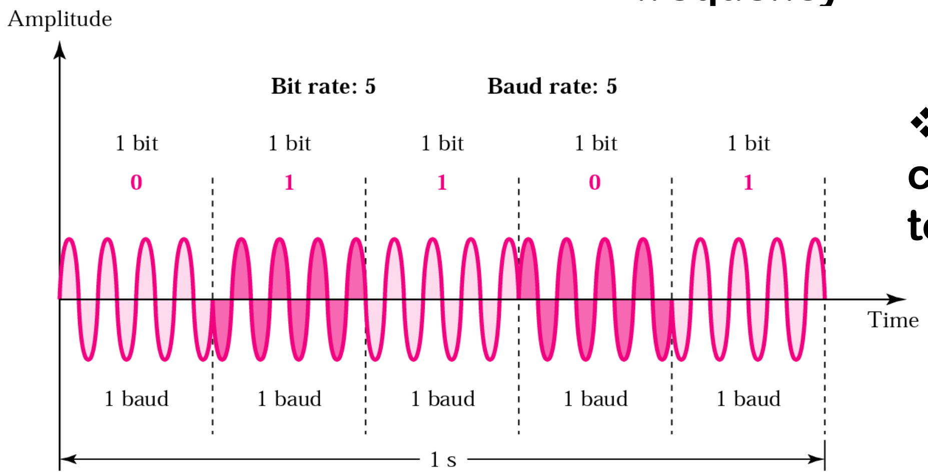
Amplitude/Freq./Phase Shift Keying





- ASK- Two binary values are represented by two different amplitudes of the carrier frequency

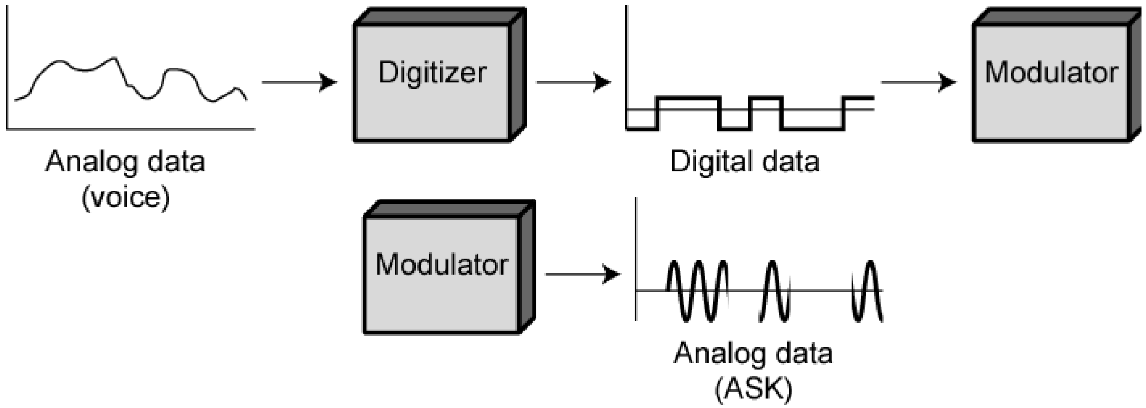
- FSK- Two binary values represented by two different frequencies near the carrier frequency



- PSK- Phase of the carrier signal is shifted to represent data

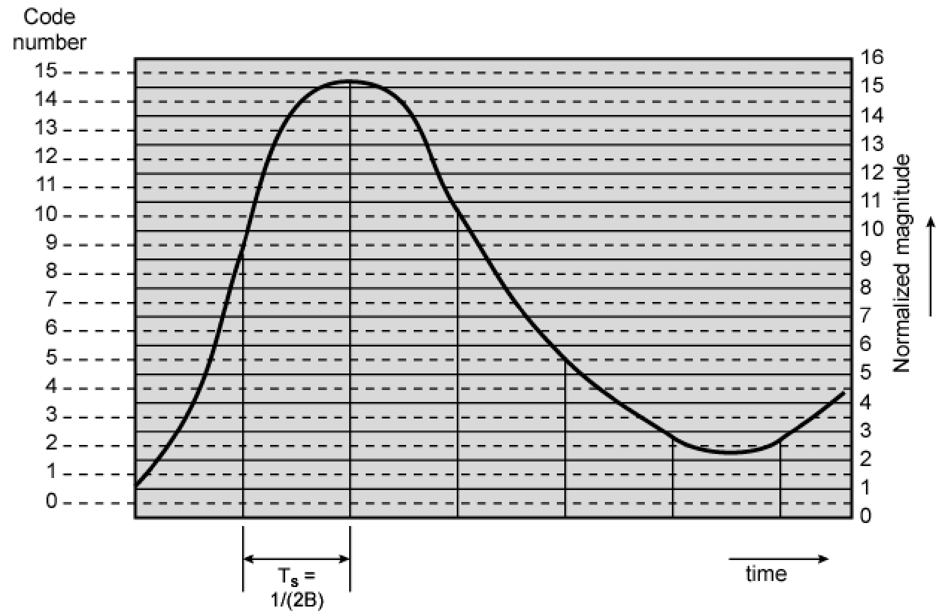
Analog Data, Digital Signal

- Digitization
  - Conversion of analog data into digital data
  - Digital data can be transmitted using NRZ-L
  - Digital data can also be transmitted using code other than NRZ-L
  - Digital data can then be converted to analog signal using modulation technique
  - Analog to digital conversion done using a codec
  - Pulse code modulation
  - Delta modulation

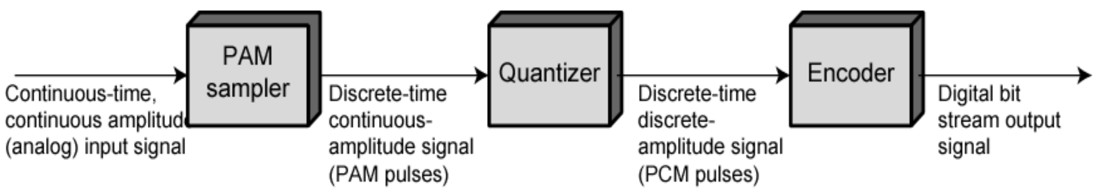


PCM Example

- If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all the information of the original signal

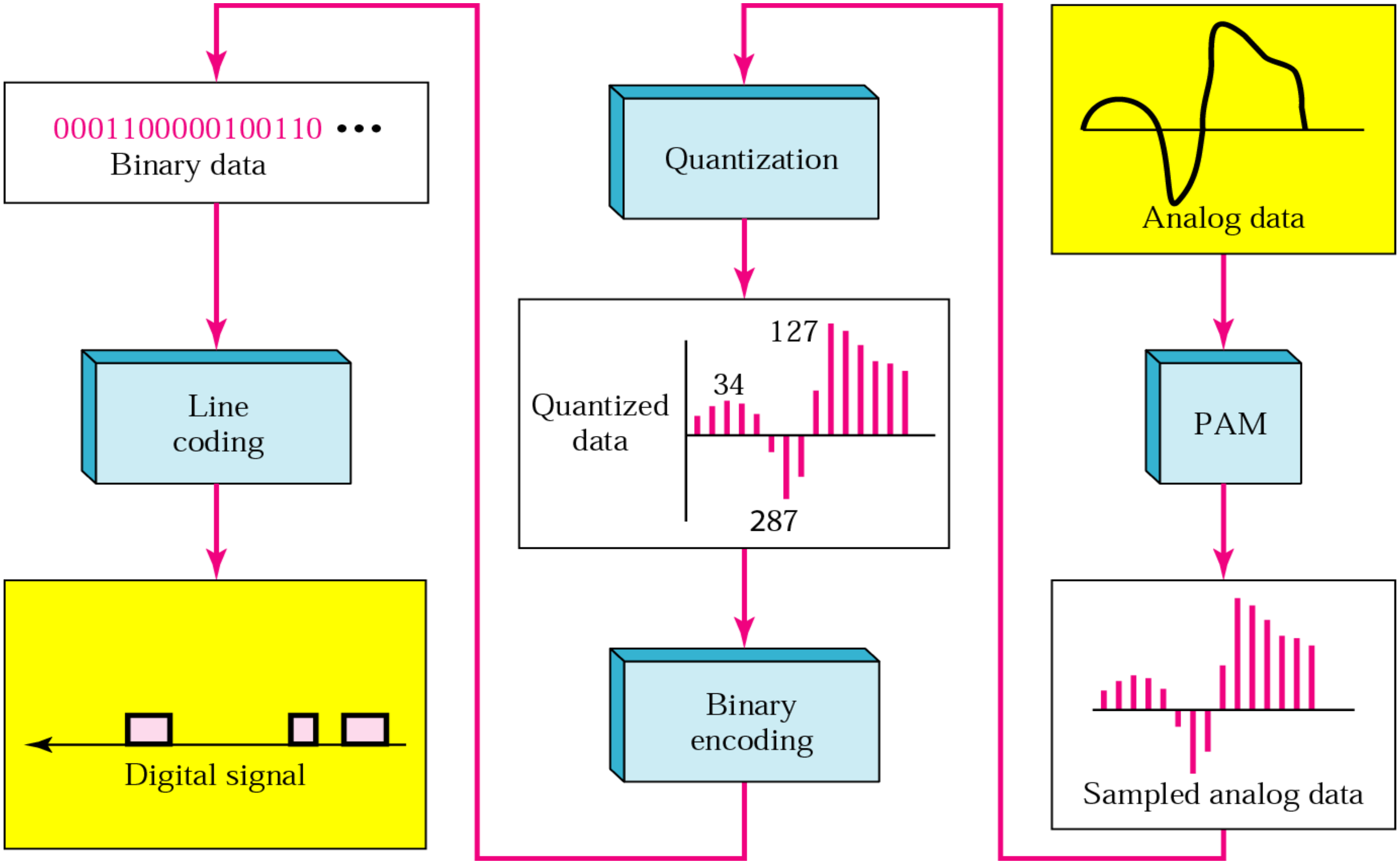


PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010



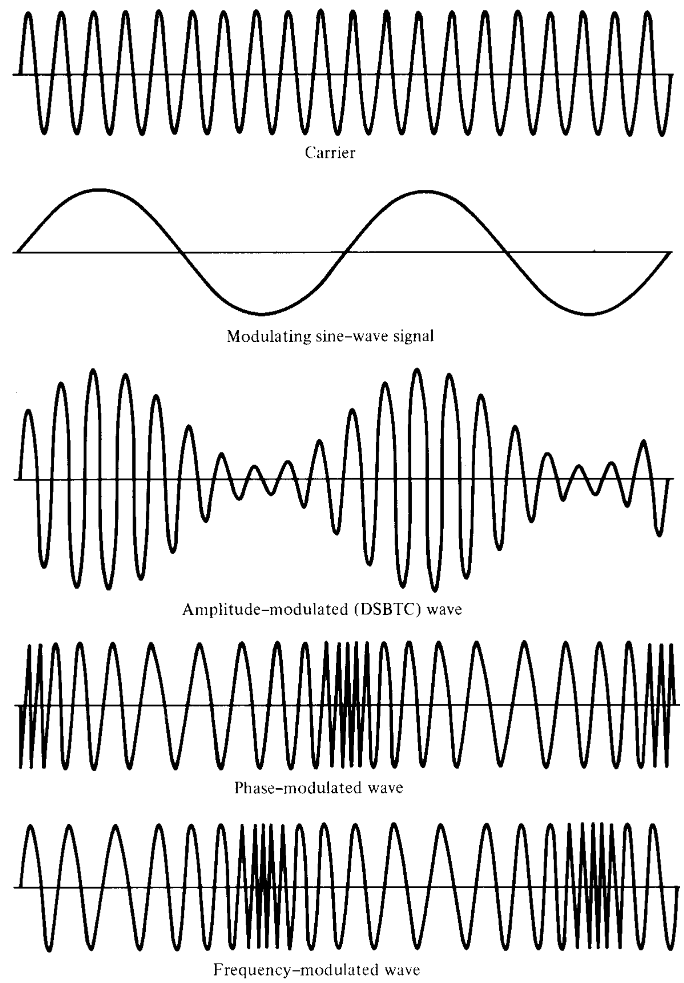
- Analog samples (Pulse Amplitude Modulation, PAM)
- Each sample assigned digital value
- Quantized
  - Quantizing error or noise
  - Approximations mean it is impossible to recover original exactly

Detailed Steps of PCM

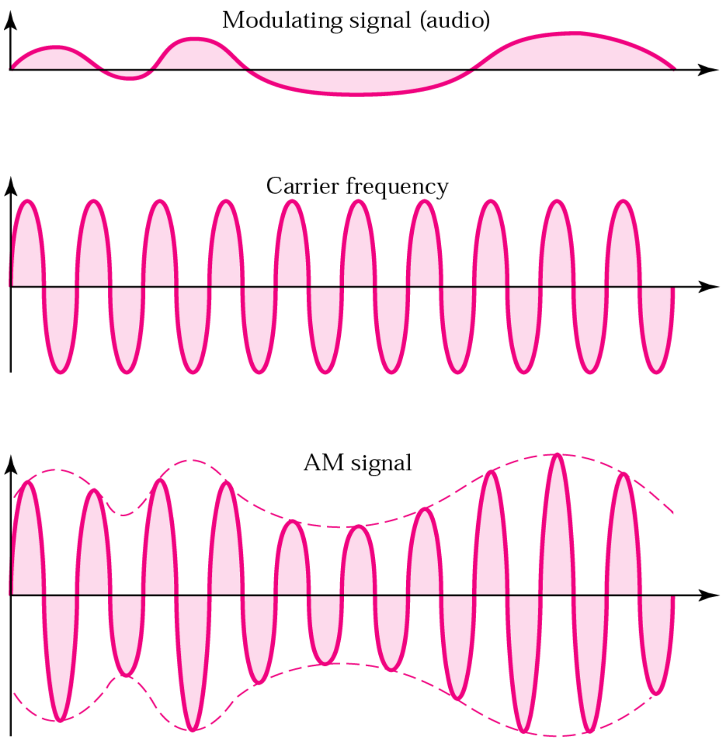


Analog Data, Analog Signals

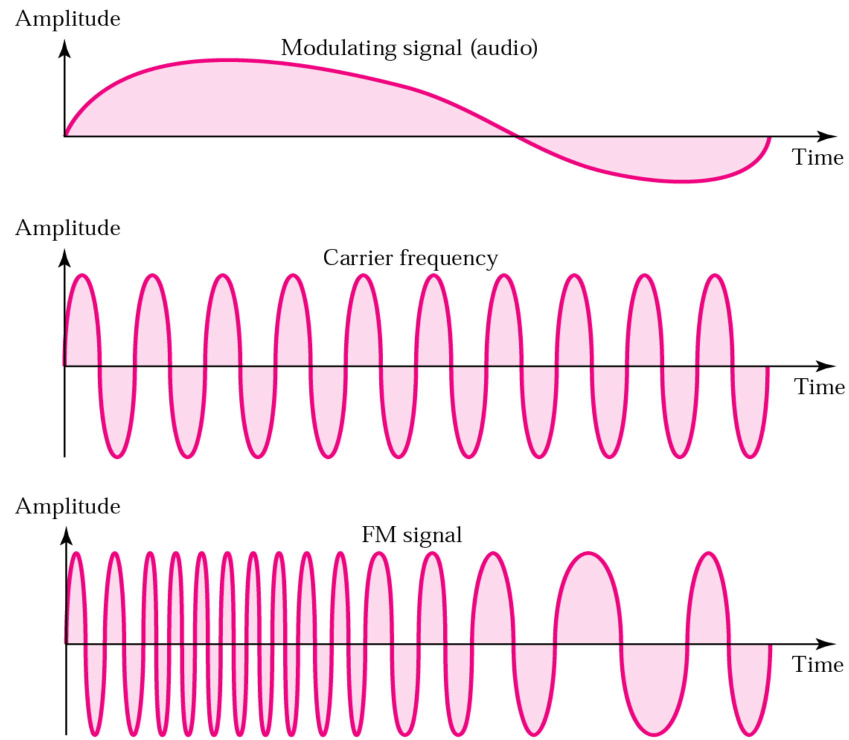
- Reasons for analog modulation of analog signals
  - Higher frequency needed for effective transmission
  - Modulation permits frequency division multiplexing
- Techniques for modulation
  - Amplitude modulation (AM)
  - Frequency modulation (FM)
  - Phase modulation (PM)



Amplitude and Frequency modulation



Amplitude modulation



Frequency modulation

Summary

- In this lecture, we have:
  - The terminology and concepts of data transmission
  - Time and Frequency Domain Concepts
  - Understood Data encoding methods

Next Time

- We will know about
  - Error Detection
- Suggested Reading:
  - Chapter 6 (Stallings)